UNDERSTANDING THE ECONOMIC IMPLICATIONS OF ALTERNATIVE ENERGY DEVELOPMENT IN EGYPT

by

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A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Honors Bachelor of Science in Economics with Distinction

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ABSTRACT

The importance of energy independence in developing nations can be the difference between development and stagnation. In the case of Egypt, although solar and wind potential are well documented, projections for the next five years are insufficient. This information could help shape the investments of both the private and public sector. The implications of this thesis center around an analysis of current challenges and risks, assessment of current energy options, and an economic outlook with regard to this energy development. Analysis focuses on wind, solar, nuclear, and hydroelectric energy, and a five-year projection showing the potential for net export by 2021 shows that economic development in Egypt could follow an energy model seen in other MENA states. Policies including fuel subsidy reduction, desalination, and international grid development are assessed. It was found that with continued alternative energy production, Egypt's peak production along with current import deals, could be up to 117% of peak energy demand, opening the door for potential net export. Economically, this development can likely create sustained jobs, infrastructure, and deficit reduction.

Chapter 1

INTRODUCTION

Egypt is at a crossroads politically and economically. The Middle East and North Africa, or MENA region, following the Arab Spring, has been host to nations transitioning to democracy and free-market economics, as well as failed-states. Following the removal of Hosni Mubarak, Egypt has teetered on the fringes of instability, held together only by a second coup d'état that has seen Egyptian leaders revert to Mubarak-like policies and authoritarianism.

Of the many issues that this new regime, lead by General Fateh El-Sisi, is facing, is one of natural resources and energy. This facet of the Egyptian economy is extremely important to its' citizens, and dually important for the creation of a sustainable economic model for development. This regime has taken steps to shifting the dynamic of energy and its relationship with economics and politics, with new plans set forth to address the currently insufficient energy infrastructure and reduce the capital expenditure per unit of energy.

Acemoglu and Robinson discuss Egypt extensively in the preface of "Why Nations Fail," a book discussing why certain developed nations take the next steps in their development while others stagnate. One theme of the preface, and in the book as a whole, is the lack of public goods in developing nations and the instability they indicate. "The protestors in Tahrir Square spoke with one voice about the corruption of the government, its inability to deliver public services, and the lack of equality of opportunity in their country"[1]. One of the chief public services that have been a constant strain on the Egyptian public are the power outages that create discontinuity in production, hazardous situations in health and public safety, and distrust in government[2]. The lack of energy development is widely accepted to create distrust in government[34]. For that reason, there is clear political and economic incentive to improving the state of Egyptian energy production and the grid infrastructure as a whole.

Energy as an Economic Concern

Energy production, grid stability and potential for expansion are paramount to the future of the Egyptian economy for a multitude of reasons. First and foremost, consistency in electricity availability sends a strong message to citizens, businesses and international institutions that public services are a priority to the new regime. This results in several positive outcomes including increased consumer confidence, increased foreign direct investment, especially in energy-related fields, as well as an improved corporate environment that will help keep Egyptian businesses in Egypt.

Further, improving energy production in Egypt to the point where Egypt becomes a net-exporter of energy will serve as a massive boost to an economy that lacks diversity and is highly susceptible to foreign shocks. Trade deficits would also be improved, and national energy production can help serve as a foundational source of revenue for a nation in desperate need of investment in all facets.

The MENA region as a whole, and specifically Egypt, is burdened with an enormous subsidy spending policy on energy[5]. This, by most estimates, is the biggest roadblock towards developing a coherent energy strategy that is reflective of Egypt's respective strengths and cognizant of the financial burden that the current system places on the government. As of 2011, Egypt's subsidy spending on energy was equivalent to 11% of GDP[6]. Considering the stage of Egypt's development, that percentage represents an enormous amount of capital that could be better leveraged to help facilitate growth.

The issue of energy subsidies is arguably the most salient issue in Egyptian economics moving forward. Not only do these subsidies create a drag on economic performance, but also their existence creates dependency that is misaligned with Egyptian competitive advantage in the form of wind and solar power. Because subsidies are chiefly aimed at petroleum, coal, and natural gas, their market effects are distortionary, allowing for excessive energy use, crowding out, and disincentive for foreign energy firms to enter the Egyptian market[7]

Moving Forward

The analysis this paper will begin with the challenges that the Egyptian economy faces with regard to energy; chiefly, the current energy market for fossil fuels along with energy subsidies. Next, analysis of solar and wind will be presented, with an emphasis on the economics of integrating those sources more prominently into the fold as well as scalability. This analysis is juxtaposed with nuclear and hydroelectric analysis, which is far more political in nature but remains an important factor to consider.

The next section of the paper will discuss the economic case for an energy regime transition, including why current circumstances, despite the volatility of the energy market, could actually prove advantageous for said transition. This section will also discuss the feasibility and potential necessity for cooperative infrastructure development across North Africa in the form of solar and wind farms.

The resulting conclusion will synthesize the importance of the energy transition that seems inevitable in Egypt, and what the economic implications of this energy regime change will be.

Essentially, analysis will feature a three pronged approach: Assessing the economic challenges Egypt currently faces, examining and projecting the extent of alternative energy development in Egypt, and analyzing how and in what manner energy development can tangibly affect the economy of Egypt.

This analysis and resulting thesis will add to the literature currently established in a novel way. While it is likely that private entities and foreign governments have done forward-looking analyses of Egyptian energy, this type of outlook is currently not present in the public discourse. This type of analysis is extremely important for the development community to help assess the extent to which energy development can aid in the growth of Egypt from a political and economic lens. Further, it is currently unlikely that the Egyptian government has been devoting research and effort to this endeavor, considering the New and Renewable Energy Authority of Egypt has not created a new report on the development of Solar and Wind energy since 2012/2013. Therefore, this type of analysis, even with the incomplete information at the public's disposal, can help paint a general picture for the energy outlook of Egypt.

Chapter 2

CHALLENGES FOR THE EGYPTIAN ECONOMY: ENERGY IS THE PROBLEM, AND THE OPPORTUNITY

Egypt is currently a nation at odds with itself economically. The World Bank categorizes Egypt as a Lower Middle Income state. In some areas, Egypt's development would make it seem like it was on pace with the Gulf States of the MENA. And in others, Egypt more closely resembles its fellow African States. Egypt's deficiencies are often a result of several core causes: institutional deficiency, misappropriation of resources, and inadequate investment in marginally productive activities. In this section, we will describe the challenges currently faced by the Egyptian economy, and illustrate how improved energy policy can help to address these enormous challenges.

Economic Development Indicators per World Bank	2008	2009	2010	2011	2012	2013	2014
GNI per capita, Atlas method (current US$)	$ 1,860.00	$ 2,140.00	$ 2,390.00	$ 2,590.00	$ 2,810.00	$ 2,940.00	$ 3,050.00
GNI per capita, PPP (current international $)	$ 9,240.00	$ 9,490.00	$ 9,700.00	$ 9,810.00	$ 10,000.00	$ 10,100.00	$ 10,260.00
GDP at market prices (current US$)	$ 162.818	$ 188.982	$ 218.888	$ 236.002	$ 262.824	$ 271.973	$ 286.538
GDP growth (annual %)	7.15	4.69	5.14	1.82	2.19	2.11	2.20
Inflation, GDP deflator (annual %)	12.21	11.17	10.12	11.60	12.44	8.99	11.48
Exports of goods and services (% of GDP)	33.04	24.96	21.35	20.57	17.43	18.06	15.19
Imports of goods and services (% of GDP)	38.64	31.60	26.59	24.69	25.85	24.78	24.05
Gross capital formation (% of GDP)	22.39	19.19	19.50	17.10	16.38	14.18	14.05
Foreign direct investment, net inflows (BoP, current US$ in billions)	$ 9.495	$ 6.712	$ 6.386	$ (0.483)	$ 2.798	$ 4.192	$ 4.783
Net official development assistance and official aid received (current US$, billions)	$ 1.742	$ 1.000	$ 0.597	$ 0.414	$ 1.807	$ 5.506	..

Table 1 Economic Indicators for Egypt, 2008-2014; Data: World Bank

Table 1 illustrates several basic economic indicators that are prudent in this analysis. Specifically, attention should be drawn to the overall reduction in economic productivity in years of political and economic instability, both globally and domestically. In 2010 and 2011, development assistance and foreign direct investment were cut drastically to the clear detriment of the Egyptian people. This coincided with a decrease in GDP growth, while inflation remained steady. Moreover, exports as a percentage of GDP has fallen consistently since 2008. While imports have also fallen, this has not occurred in equal proportion, leading one to conclude that Egypt’s trade deficit has continued to grow.

Moreover, the status of the Egyptian economy with regard to investments, corporate environment, and debt should be assessed to accurately depict the situation. If the Egyptian government’s plan to use energy as an economic tool for development is to move forward, these challenges will absolutely need to be kept in mind while considering the transitions that are being suggested.

Current Economic Environment

The Egyptian economy is reflective of its political disorder[8]Years of authoritarian rule and mismanaged finances have left Egypt in a situation similar to other post-colonial states in the MENA region.

Debt to GDP is an extremely important principle for developing nations as it often qualifies, or disqualifies, certain international loans for development projects, along with influencing the confidence with which private investors can invest. Additionally, high debt-to-GDP ratios often push away investment. With the recent debacle in Greece, the international investment community now is even more sensitive to the risks associated with high levels of debt, even in “stable” western economies. For nations categorized as Lower Middle Income, this standard would be doubly important.

In Figure 1, the Debt to GDP ratio is illustrated. Amongst developing nations, it is typically considered dangerous once that ratio reaches 90%. In the case of Egypt, 2014 seems to be a recent peak, with a 90.5% debt to GDP ratio. Since 2008, the ratio has continued to increase, likely due to a combination of political and economic factors that drove government borrowing. The Debt-to-GDP ratio in Egypt is expected to decrease in years to come due to subsidy cuts and international economic growth, especially in the MENA region, returning to positive, above 3% growth.

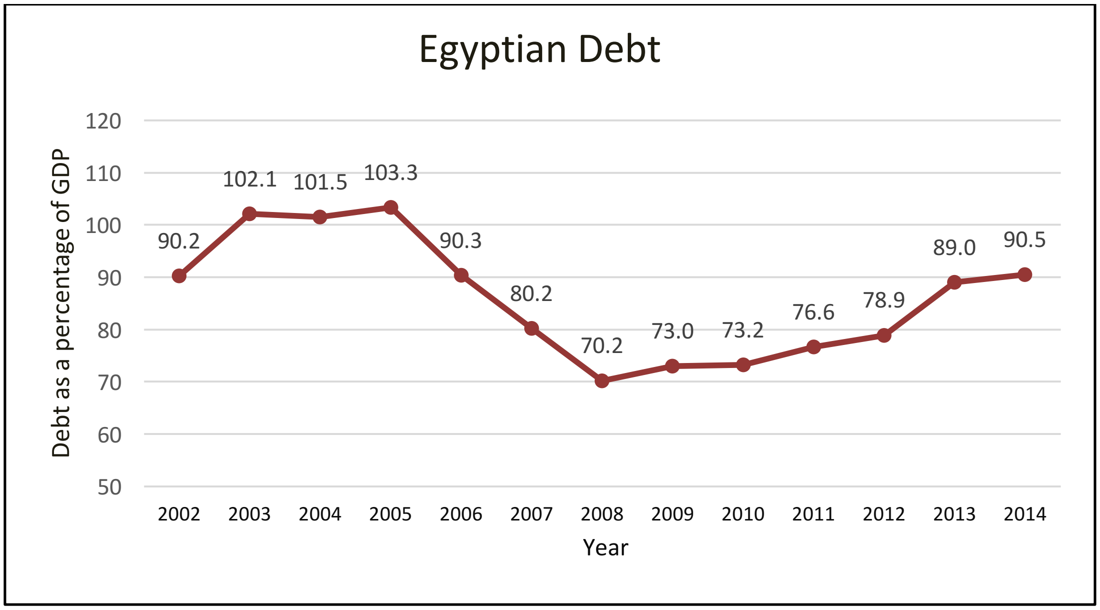


Figure 1 Egyptian Debt-to-GDP ratio. Data sourced from IMF

Population and Growth

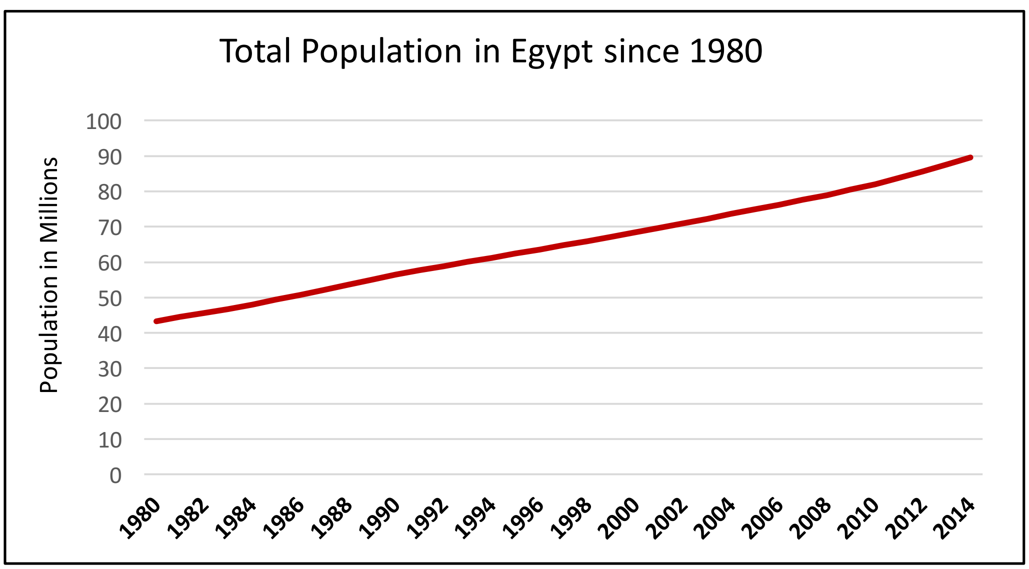


Figure 2 Egyptian population, Data sourced from World Bank

The population of Egypt is currently around 83 million, and is projected to continue to grow robustly, despite efforts by the government to effectuate a population plateau. This population growth has the potential to be detrimental to Egypt's economy if investments are not properly constructed around the surrounding externalities that population growth creates[9].

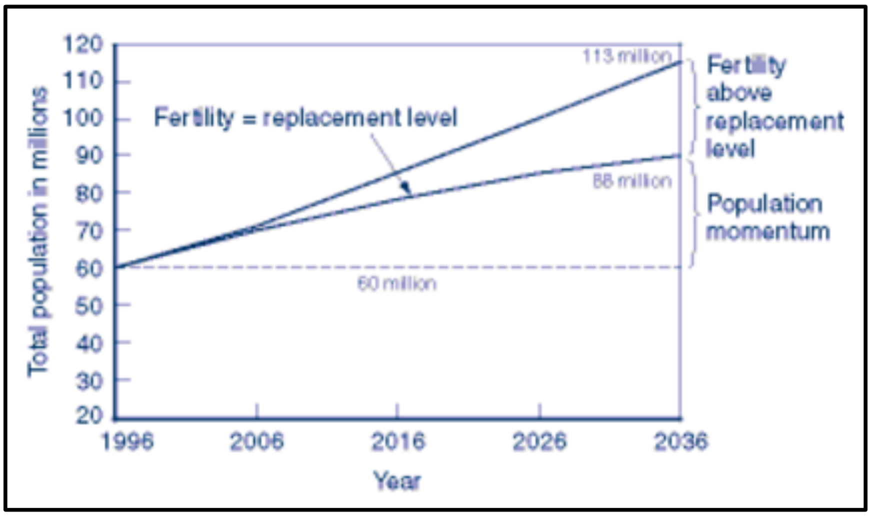


Figure 3 Projected Population Growth[10]

Egyptian population growth has direct implications for the economy; reducing population growth can help to curb the need for new jobs, education and health spending in an economy that is pivoting[11]. The above figure illustrates that vast gulf if Egypt fails to curb population growth in a sustainable manner. This will become exceedingly important when modeling future electricity consumption as well, in order to see if the Egyptian governments current expansion plans can compensate for the additional populous.

Furthermore, a growing population with the same energy consumption habits that are embraced by the Egyptian population would lead to much higher spending on energy. This, combined with the other spending that Egypt would inevitably be forced into with an even larger population, especially with demographics shifting towards younger children still being serviced by public education, would necessitate further government spending. Likely, this could mean greater deficits, unless the government reforms being enacted are indeed followed through upon.

Subsidies

One area in which reforms are beginning to take shape is with regard to subsidies. In Egypt, energy subsidies have been an important part of policy to keep the general public happy and capable of conducting business. Generally, these subsidies have allowed for petroleum, gas and electricity prices to be reduced for public consumption. However, this has created multiple unintended consequences that have negatively impacted the economic performance of Egypt while simultaneously increasing budget deficits[12].

The first of these negative externalities of the enormous energy subsidy program in Egypt is the proportion of spending that has been directed into said programs. In 2014, it was reported that 1/3 of Egypt's budget was dedicated to subsidies of all kinds, with approximately 75% of that portion dedicated specifically to energy[13].

2014 represented the beginning of the winding down of the subsidy program, but prior to that, it had been an immense undertaking by the government in Egypt. In 2011, post-tax subsidies for petroleum products represented 39.07% of government revenue[14]. This, along with subsidies for other forms of energy, equated to approximately 11% of pre-tax government spending. For context, this represented approximately twice as much spending as Egypt's government appropriated for education and for health.

While it appears that the government has been reducing subsidy spending, there is reason to question the long-term ability to keep subsidy spending low. Crude oil prices are near the 15-year low, adjusted for inflation. The following chart also illustrates this phenomenon[15]. This represents a dilemma for the Egyptian government. Currently, it is much cheaper to subsidize the price of petroleum due to the low-cost of crude oil, but as oil crawls back to its average, subsidy spending will inevitably increase, or the cost for the Egyptian consumer will drastically increase. This phenomenon is illustrated in the below figures.

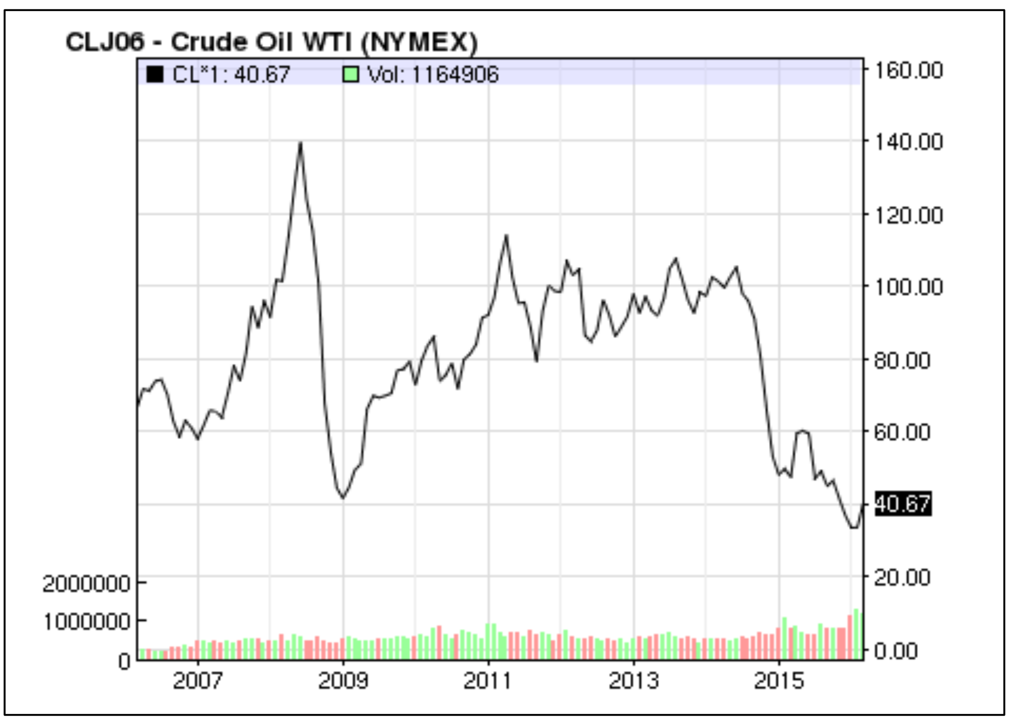


Figure 4 Crude Oil prices, 2006-2016. (Price per barrel, adjusted)[16]

From an economic perspective, a decrease in price that occurs through the international energy market helps to artificially reduce subsidy costs. As the market normalizes, however, there are two major risks as potential outcome: increasing subsidy spending to keep the artificially low energy prices stable, or a static subsidy that allows prices to return back higher.

The first potential outcome, increasing subsidy spending, would be a reverse of recent policy direction and would undermine the work being done to reduce the deficit in Egypt. On the other hand, it would allow for the public to keep hold of cheap energy prices, something profoundly important to the current populous.

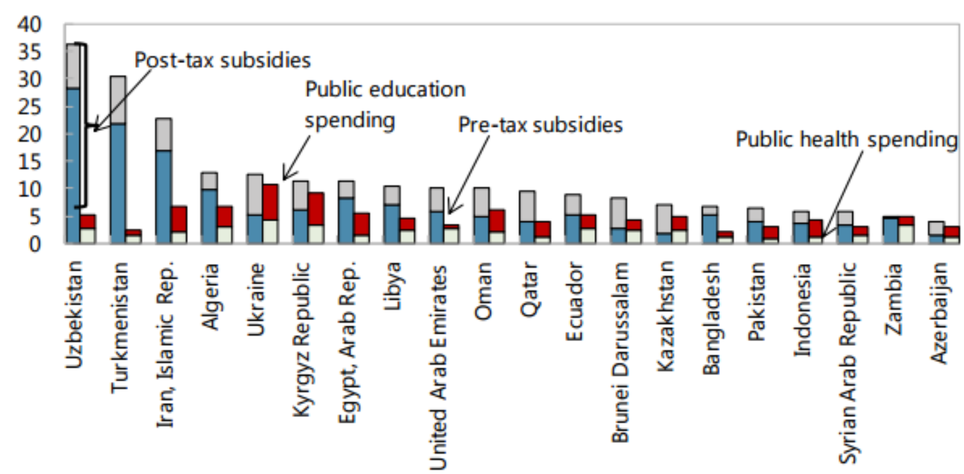
If the Egyptian government were to allow prices to return back higher, the Egyptian public would surely be outraged at the volatility in energy prices, however the government's spending would not be affected.

Therefore, policies that help to curb volatility of prices while simultaneously working to improve the debt crisis in Egypt are of paramount importance. Surely, the Egyptian government will not be able to solve this issue without support from the public.

While price volatility is a current issue with regard to energy subsidies, there are other issues as well that will prove important as Egypt reforms its energy policies. Among these is government crowding out of energy investments and over-use of energy resources due to their artificially low price.

(Percent of GDP)

Subsidies are substantially higher than critical social spending in many countries.



Sources: International Energy Agency; World Bank; Clements, Gupta, and Nozaki (2012); IMF staff estimates; and Organisation for Economic Co-operation and Development.

Note: Health and education spending are for 2010 or latest available.

Figure 5 Sourced from IMF Subsidy Reform Briefing, 2013

This graphic from a recent IMF report on subsidy spending illustrates the crowding out effect with government subsidies. The government's high-spending on short-term subsidies are problematic: they create an inability to invest in long-term projects or other forms of spending due to limited financial capacity. In essence, developing nations spending on subsidies is an inefficient process because the positive externalities associated with energy subsidies are greatly disproportionate than that same spending on things such as health or education. Therefore, when the government has a limited amount of resources to spend on, and it chooses to do so on a less productive activity, such as energy subsidies, it is in effect crowding itself out of more productive spending.

While there can also be an argument to be made for crowding out of investment into the energy industry in Egypt, the bigger problem is competitiveness. Between 2009 and 2010, 70% of the Foreign Direct Investment into Egypt was related to energy, mostly petroleum and natural gas[17]. With the recent volatility in the market, this will likely be decreasing as more recent data becomes available. However, nonetheless, natural gas and crude reserves in Egypt have certainly piqued the interest of many international energy firms. While in many ways this helps bring in additional business into Egypt, it crucially allows foreign firms to grow, when the domestic industries have been priced out due to subsidies for so long, making for an anti-competitive domestic environment.

The artificially low price that subsidies create for energy also incentivizes an economically inefficient amount of energy resources being utilized. This includes incentivizing capital intensive, as opposed to labor intensive, industries as well. This market distortion can have lasting economic effects if not reversed. Mostly, this means a lack of competitive Egyptian industry on a global scale as well as resources available for development now and in the future as opposed to immediate consumption.

Corporate Environment

The corporate environment in Egypt is another problematic policy challenge that the government will need to confront in order to enable greater economic development to occur. Egypt's main strengths lie in its ability to attract tourists along with their strong IT infrastructure[18]. However, overpopulation and geopolitical issues (i.e. terrorism) continue to be seen as long-term threats to successful business development in Egypt.

(Scale: Rank 189 center, Rank 1 outer edge)

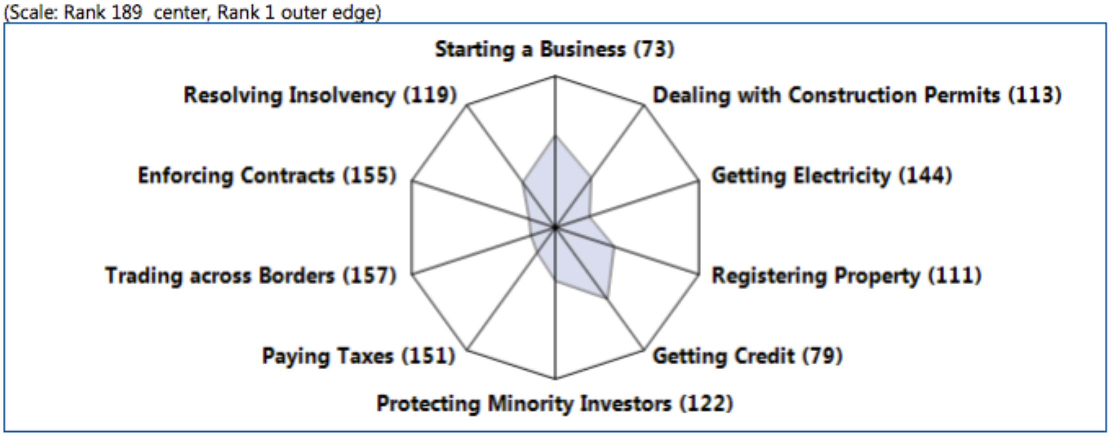


Figure 6 Ease of doing business in Egypt

Figure 6 is taken from the Doing Business database and shows the difficulty that businesses starting in Egypt must go through[19]. This level of difficulty combined with layers of corruption[20] is indicative of a situation in dire need of action if Egypt plans on competing regionally in an economic manner.

Water and Environment

Further, as a result of climate change, population pressure, and external pressures from projects such as the Millennium Dam in Ethiopia, water will continue to be an increasingly pressing problem in Egypt, along with erosion and desertification[21].

The following figure illustrates that, even under a new, more water efficient regime, Egypt's GDP along with the majority of the MENA region, is subject to a detrimental economic situation due to the scarcity of water by 2050[22]. Therefore, this is another challenge that must be considered by the government – and not just becoming more water efficient, but potentially finding new, scalable methods of finding potable water for the population and for the purpose of maintaining economic growth.

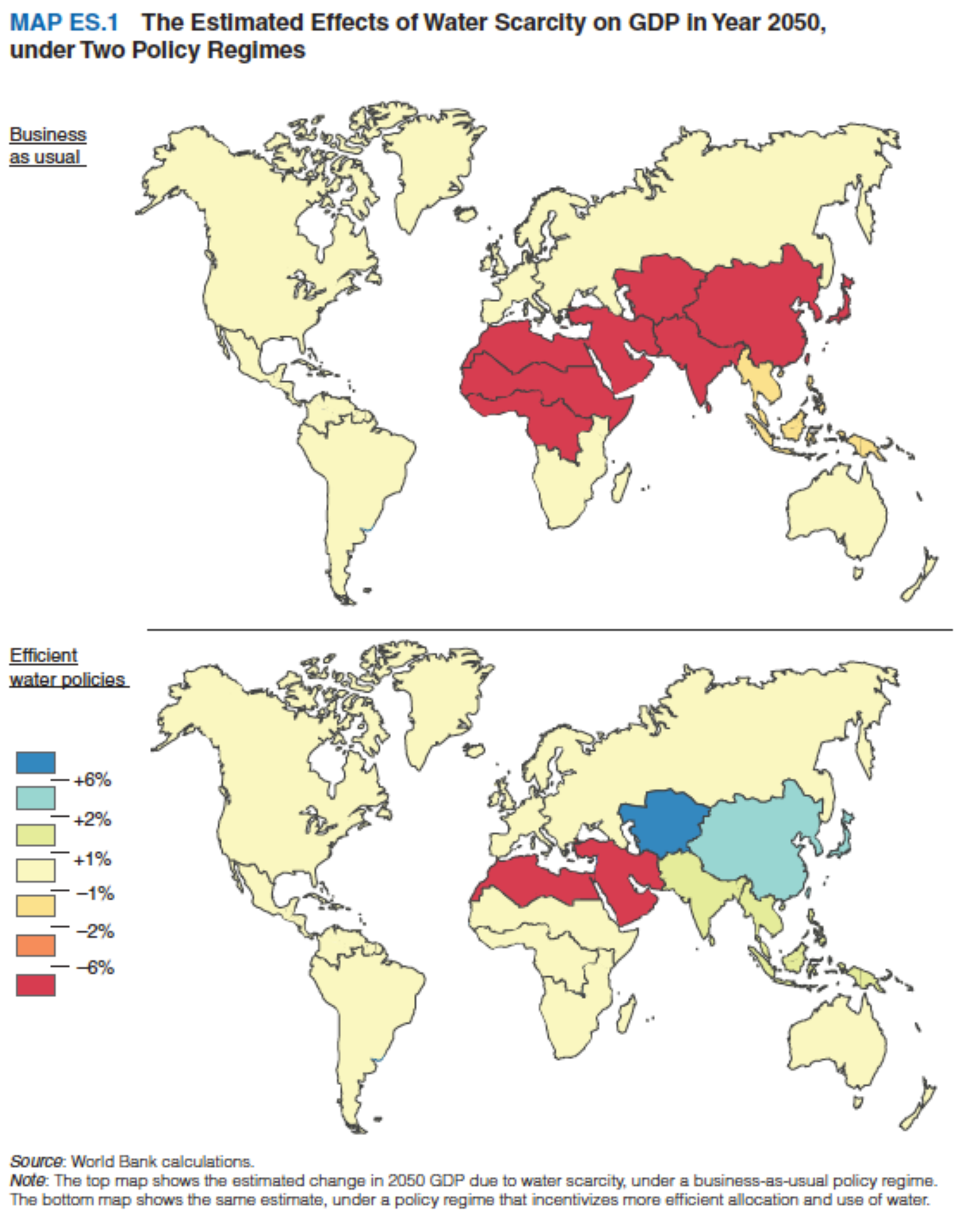


Figure 7 Illustrating the impact of water scarcity, in particular Egypt and the rest of the MENA[23].

Chapter 3

WIND POWER

Wind power is considered one of the cleanest forms of energy currently available for large-scale production. Wind turbines harvest energy by using the energy potential in wind to rotate a generator, which allows magnetic potential energy to be transferred to electricity and directed into a grid.

The conditions that create an ideal situation for wind turbines geographically are the following: "Places with the best conditions for producing strong, steady winds include rounded hilltops, mountain gaps, open plains, shorelines and over the ocean. Please see the U.S. wind resource map on this page for further details. Wind farms can take up a lot of land, but the majority of the land can still be used for other purposes like farming, ranching or recreation,"[24].

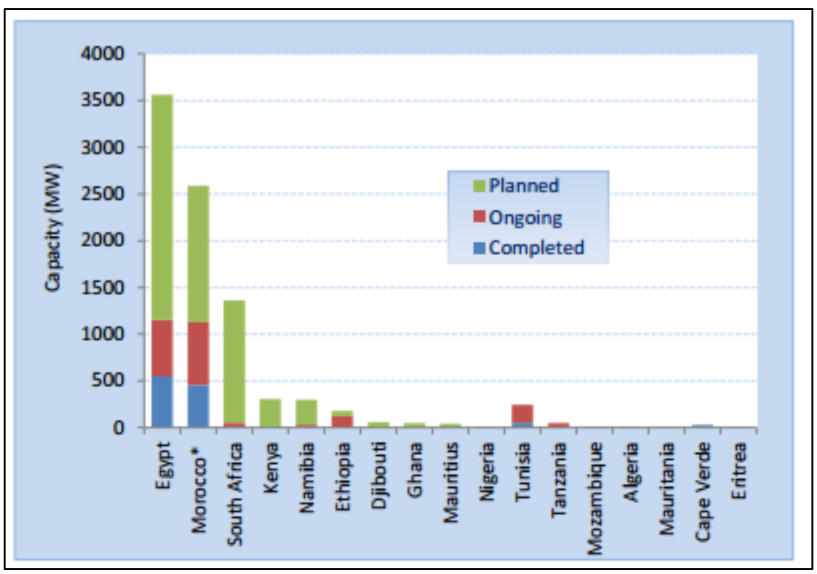


Figure 8 Current status of wind development throughout Africa[25].

Geography

For Egypt, wind energy is geographically advantageous. With two coasts lines totaling 2,450 km and ample, unused land, Egypt is in a premium position to take advantage of wind power[26].

The following figure illustrates the different areas in Egypt with respect to average wind speed. Wind turbines typically need a speed of 9mph, approximately 4 meters per second, to function effectively.

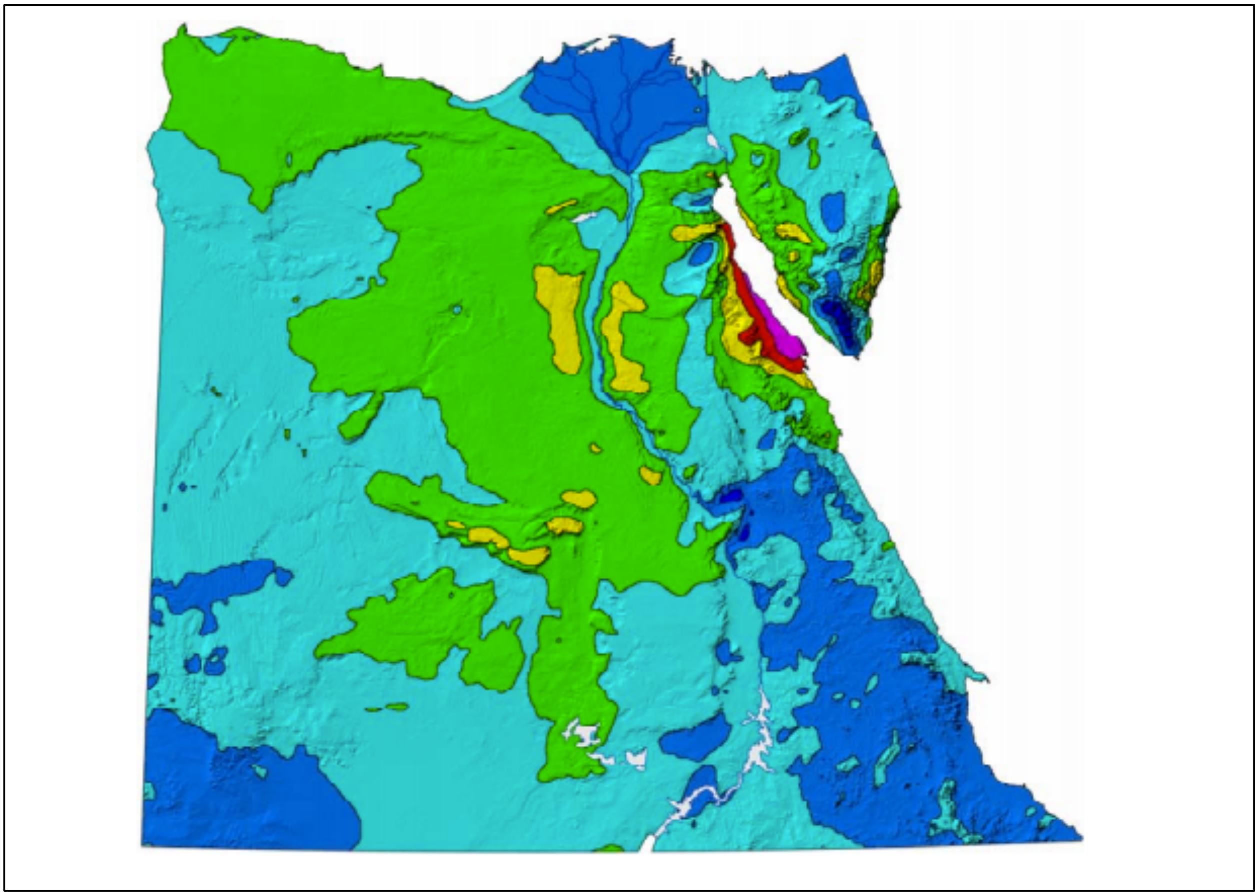


Figure 9 Map of Egypt graphed with corresponding wind intensities

"The predicted wind climate of Egypt determined by mesoscale modelling. Map colours show mean wind speeds in [ms-1] at a height of 50 m over the actual (model) land surface: blue 4-5, cyan 5-6, green 6-7, yellow 7-8, red 8-9, magenta 9-10 ms-1. The horizontal grid point resolution is 7.5 km"[27].

As you can see, the entire geography of Egypt is conducive, at least with regard to wind speed, to wind turbine placement. Most specifically, the region on the eastern coast, adjacent to the Red Sea, is the most premium area for turbines. The existence of a certain large portion of land that is especially conducive to wind power development will become especially important in later discussion of economic planning with regard to wind farms.

Current Status of Wind Power

Wind power has steadily increased its importance in Egypt's energy market since 1997. The following figure illustrates the growth in the wind power market since 1997. The majority of the wind energy in Egypt is sourced from just two major wind farms: Zafarana and Hurghada, producing 545 MW and 5 MW respectively[28].

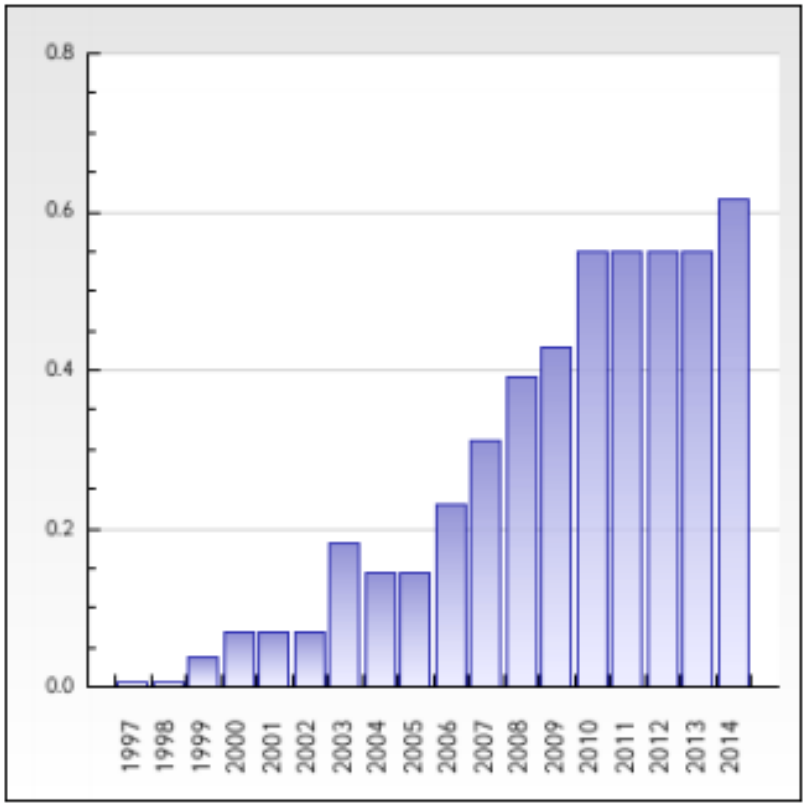


Figure 10 Wind Market Size in Giga-Watts

As you can see, this makes up the vast majority of Egypt's wind capacity. However, on the whole, this level of output is negligible in a country-wide sense. Wind represents less than 1% of Egypt's total energy consumption. In 2015, electricity demand was approximately 30 GW at its' peak. If we assume that all wind power harvested is put into the electrical grid, then wind power at its peak represents only 2% of electrical capacity.

Plans for Development

Currently, Egypt's plans for wind development are expansive, but also not enough. In the New and Renewable Energy Agency's (NREA) 2012/2013 Annual Report (the latest available)[29], government plans are detailed for government and private funded wind farms to expand wind energy capacity. The NREA hopes to have 7.2 GW of installed capacity by 2020, but also makes the goal of having 12% total generated

electricity in Egypt created through wind farms.

Project	Capacity	Cost (Millions, €)	Expected Implementation Date
Hurghada Wind Farm	5MW	N/A	1993
Zafarana Wind Farm	545MW	N/A	2001 through 2012
Gabal Al Zayt (1)	200MW	340	2016
Gabal Al Zayt (2)	220MW	308	2018
Gabal Al Zayt (3)	120MW	168	2018
Gulf of Suez (1)	200MW	280	2018/2019
Gulf of Suez (2)	200MW	280	2019/2020
Gulf of Suez (3)	200MW	280	2019/2020
West of Nile (1)	200MW	280	2019/2020

Table 2 Government Wind Development Projects, Parenthetical Annotation refers to the stage of development. Source: Author's compilation of NREA data

The above table illustrates the implemented and planned government wind projects. Projects that have yet to be implemented had been pushed back two years due to the political instability faced by the government, but are still being planned with partners in Europe and Asia, particularly Germany, Spain, Denmark, and Japan, all moving forward.

The push for private investment is also a priority for the Egyptian government. Currently, there are four separate plans for private wind farms to develop in the Gulf of Suez. The Egyptian government hopes to vary and diversify the types of owners and ownership by implementing Build-Own-Operate plants, plants that are strictly private, as well as the usufruct system, which essentially refers to leasing government land for a relatively long time, typically between 50-100 years.

Project Location	Capacity	Expected Start	Type
Gulf of Suez	250 MW	2018	BOO
Gulf of Suez	500 MW	2019/2020	BOO
Gulf of Suez	120MW	2018	Private
Gulf of Suez	600MW	2018/2019	Private/Usufruct

Table 3	Private Wind Energy Development Projects Source: Author's compilation of NREA data

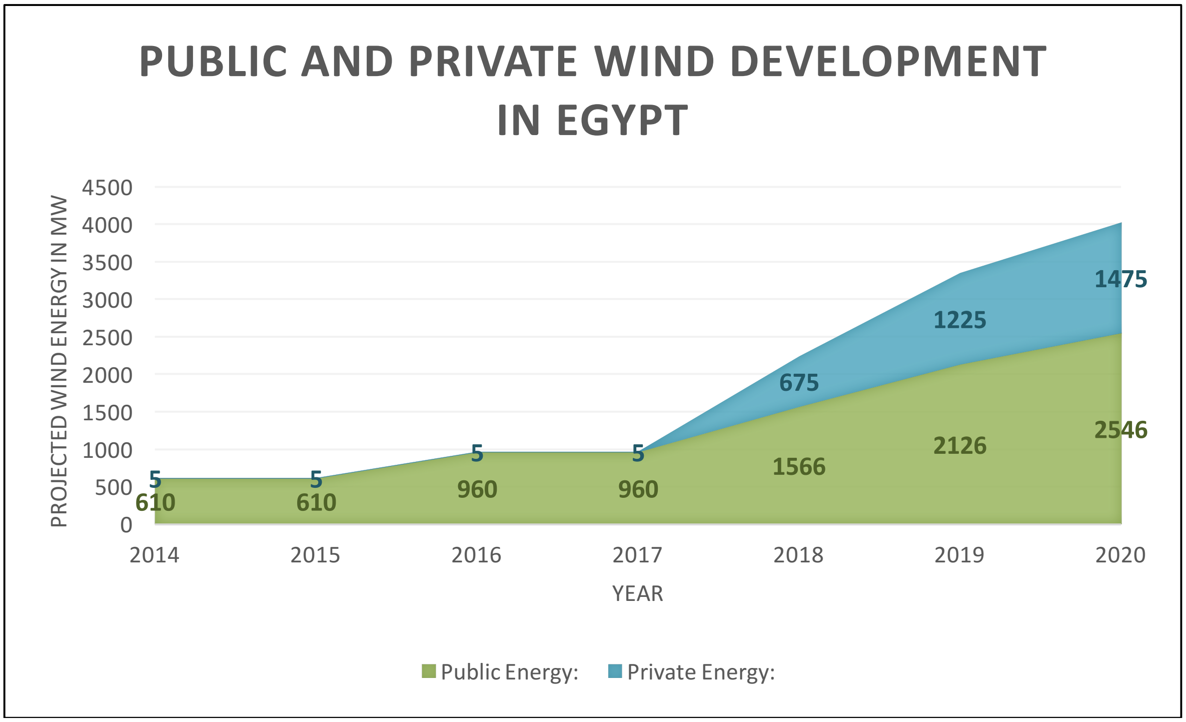
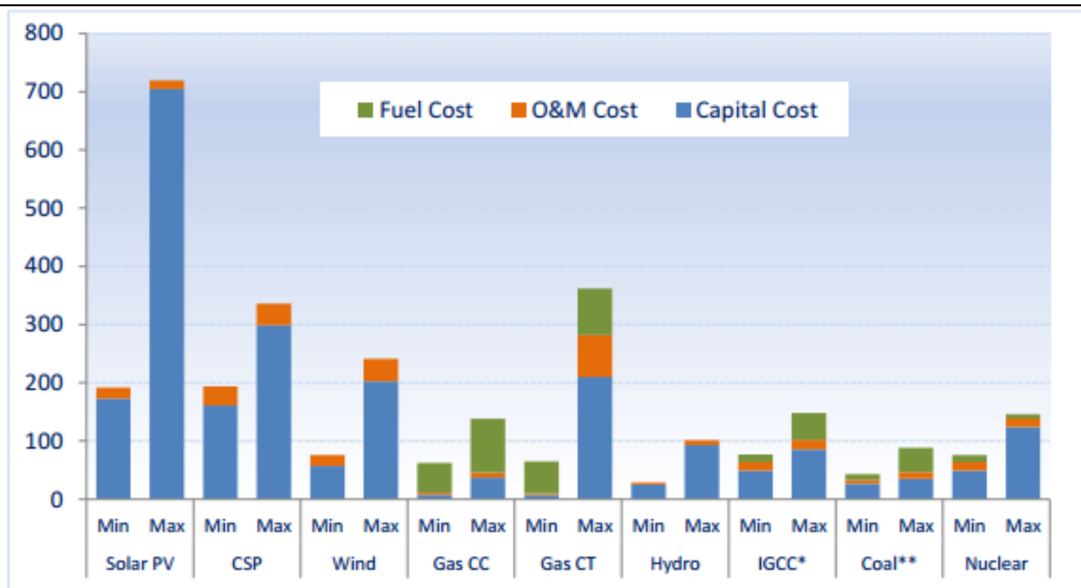


Figure 11	Combined Public and Private Wind Initiatives Planned to 2020, Assuming Two-Year post-revolution lag. Source: Author's compilation of NREA data

Figure 3 illustrates the growth in wind energy expected up to 2020 according to the NREA. Significantly, it also shows a huge shift from almost entirely government produced wind energy to a healthier mix of public and private. By 2020, the government expects that approximately 37% of wind energy will be produced by the private sector. It is important to note, however, that these are likely optimistic projections even given the two-year lag, due to the status of the economy and geopolitical conflicts in Egypt and abroad.

Economics of Wind Energy in Egypt

A mix of 37% private energy production would be a large step in the right direction for the Egyptian economy, as it would signal that innovative government-led industries are being effectively transitioned into the private sector. This can, in effect, help to signal to investors that private energy investments, particularly in wind energy, can be successful and profitable.



* IGCC with carbon capture and storage, ** Supercritical coal. Solar PV- Solar Photovoltaic, CSP - concentrated solar power, Gas CT - Gas combustion turbine, Gas CC - Gas combined cycle, IGCC - Integrated gasification combined cycle, O&M – Operation and Maintenance

Source: World Bank, 2011

Figure 12 Levelized cost of energy in USD per MWh produced[30]

Figure 12 illustrates why economically, Wind is and will continue to be a mainstay in Egypt and other developing countries. As illustrated, the cost of wind energy is currently slightly more expensive than gas, the source most widely used currently in Egypt. However, the difference in costs is negligible if wind farms are optimally efficient, in the case of the "min" bar illustrated in the figure. Further, noting that there are no fuel costs, this ultimately means that there is inherently less volatility in cost between Wind and more traditional fuel sources. This volatility more developing nations, especially ones with robust subsidies programs such as Egypt, can be devastating. The ability for wind energy to be produced reliably, efficiently, and in combination with other traditional sources means a diversified energy portfolio that hedges against international market pressures.

Another important note in the development of Wind energy industries in Egypt, along with other developing nations, is the ability for economies of scale to develop and significantly reduce costs as well as barriers to entry. This not only refers to obvious things such as production, but also infrastructure and grid connection. The more wind farms an area has, the cheaper and more quickly new farms can come online and begin contributing to the grid.

The African Development Bank Group discusses this extensively in their wind energy report. In comparing the relatively cheaper costs of development in Egypt/Morocco versus South Africa, the author states: "In Egypt, several projects have been planned or implemented in close proximity (for example, the 8 and 6 individual projects at Zafarana and the Gulf of Zayt wind farms respectively); such occurrences significantly reduce the need for new ancillary infrastructure. Meanwhile, South

Africa's projects are located in different coastal areas of the country, hence the need to integrate new ancillary infrastructure in the projects."[31]

Essentially, the magenta area in Figure 2 contains the vast majority of Egyptian wind farms. This allows the cost of ancillary infrastructure such as grid connection and the necessary roads, maintenance areas, etc. to be marginally reduced with each additional wind project in Egypt. This sentiment is echoed by the author: "Yet, there are few markets where trends can be deduced – Egypt, South Africa and Morocco – where wind farms are located in similar geographic areas, and there is a large enough sample. We find that costs per unit are on marginally decreasing trend only in Egypt."[32] This is excellent news for the NREA, international and domestic investors, and the wind energy community as a whole. The ability to see marginally decreasing cost trends in the development of wind farms in the nascent Egyptian wind industry indicates that not only can wind power continue to be reduced in cost, but it can be done in the developing world as well. More specifically, however, the efficiency, proven success, and cost-reduction in Egypt may make it a more promising investment than other African nations for investors wishing to enter the wind market in the MENA or Africa.

Chapter 4

SOLAR POWER

Solar power is an intriguing prospect to many scientists and climatologists due to its abundance and access. However, there is rightfully a good deal of skepticism regarding its wide scale adoption, especially in developing nations. Critics of solar power cite its expense, intermittence, and perceived lack of reliability33 as reasons why nations, especially those in fragile political, economic or social condition, should not rely on it.

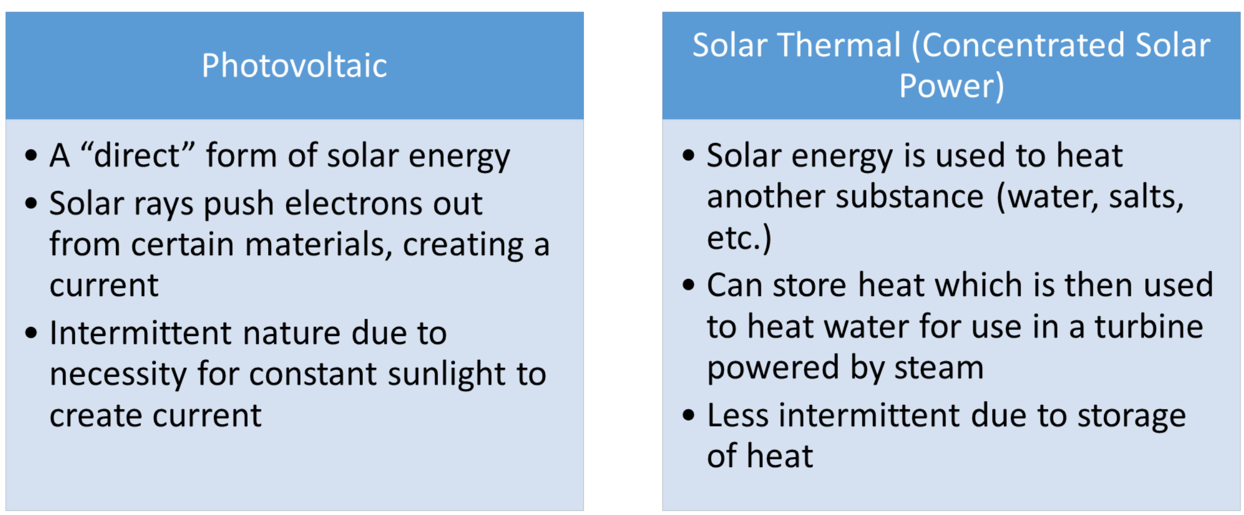


Figure 13 Brief descriptors of the two types of solar energy discussed in this section

The above figure illustrates the two separate types of popular solar energy harvesting. This is important to keep in mind as they can often serve different functions, either complementary in nature or as substitutes. Furthermore, they are often priced differently, as is expounded upon in Figure 3.

This section will feature a case study on Morocco's solar adaption, due to its' numerous similarities to Egypt both with regard to development and geography. Following the Morocco case study, a discussion of geography will follow, along with the development of solar power and future plans.

Morocco: A Case Study of Solar, a Lesson for Egypt

The number of developing nations utilizing solar power and creating plans to embrace it continues to grow. The reason for this has been the backing of international organizations and developed states in the financing of these projects. One example of this that should be used as a model for Egypt is the newly constructed solar plant in Morocco, which is providing power to up to $1 million people[34]. Financed in part by the World Bank, this project is a pivotal step in the development of North African solar power from an international perspective.

The Morocco Noor I plant is seen as a model for developing nations for multiple reasons: financing, technology, and output. The Noor plant uses Solar Thermal power, mitigating some of the risks of solar detractors. It does this through Solar Thermal technology, which allows for solar panels to heat up large amounts of water, which then becomes steam to power turbines. This is, in many ways, a safer option for many geographical areas due to this technology's ability to store heat. Other forms of solar energy would potentially, for example, become weaker as clouds pass overhead, whereas solar thermal technology can maintain a constant output even with intermittent cloud coverage. This is ideal for a situation such as Morocco as well due to the natural sunniness it experiences, meaning that cloud coverage will be rare to begin with.

The example of Morocco is important for a multitude of reasons: Geographic similarity to Egypt, similar political circumstances, along with similar potential international partnerships for energy development. Therefore, viewing the development of solar power in Egypt through the lens of this Moroccan solar project will be a helpful exercise in assessing solar energies' implications in Egypt.

Geography

Geographically, solar farms ae similar to wind farms in that they require lots of open space. Egypt's large swaths of open space make solar farms, just like wind farms, a distinct possibility.

Only 6% of land in Egypt is occupied by people, and much of the rest of space is potentially availably for energy creation in various forms. The availability of space is a crucial component of solar development. The Noor project is expected to be over 1,000 acres large. In some developing nations, this is clearly problematic, however in nations that have large areas of unused land, especially desert land, this is not a systemic issue.

As the following map illustrates, the entirety of Egypt maintains steady, high levels of irradiation. This is pivot in solar systems – having not only consistent but powerful sunlight makes solar power much more efficient with greater output. According to the World Meteorological Organization, Egypt averages only 14 days of rain a year. In desert areas, this number is even less, meaning that sunlight, and hence solar power, can be effectively leveraged as a consistent power source.

This is because of Egypt's location on the global sun-belt, essentially an area that stretches across North Africa and into the Middle East that receives consistent, powerful sunshine and minimal deviations in climate. Morocco and Saudi Arabia are also nations that are part of the global sun-belt, explaining the importance they place on developing solar energy.

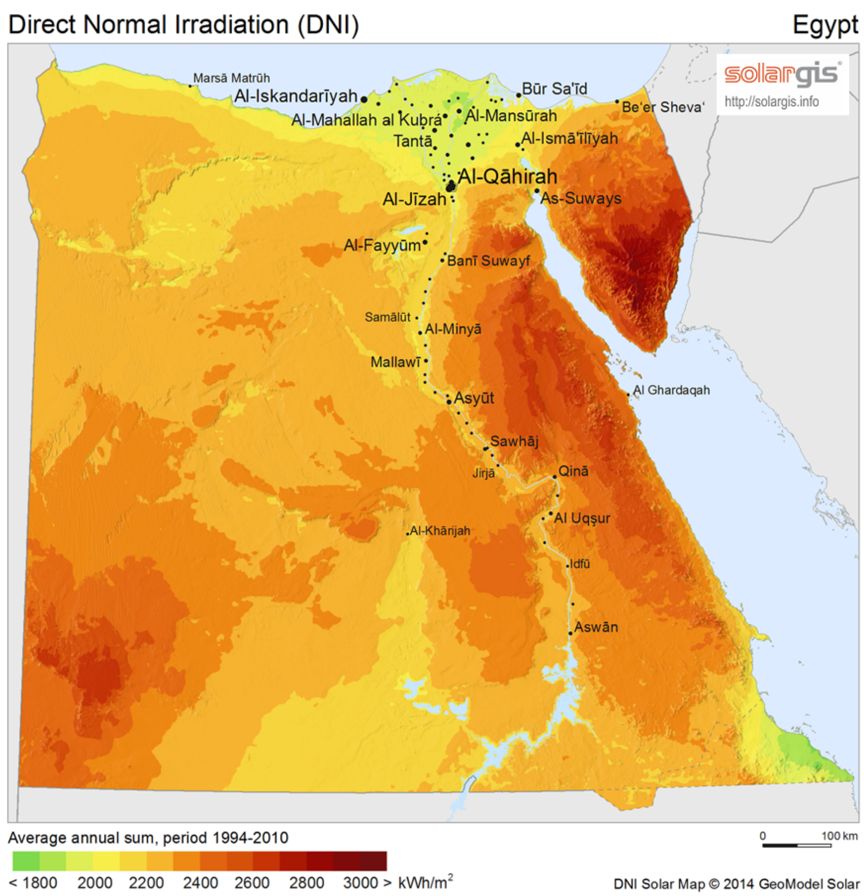


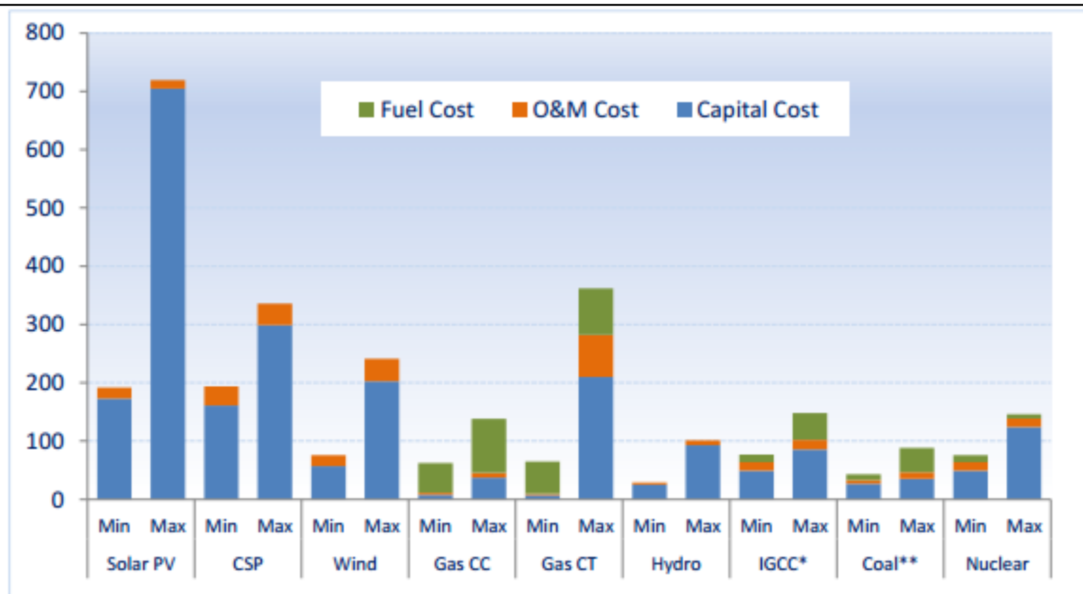
Figure 14 Map of Solar Irradiation in Egypt, Source: SolarGIS

Egypt's geography is clearly extremely conducive to solar power. The international community consistently refers to Egypt as a potential "solar powerhouse" for a reason. This is clearly intriguing given the amount of irradiation Egypt is exposed to.

Therefore, it is prudent to explore what Egypt is currently harvesting in the form of solar power, and further, its future plans for solar power. These plans, both current and future, will be extremely important in analyzing the scalability and potential of solar energy in the context of Egypt's geography.

Current Status of Solar Power

Egypt's solar capabilities are currently constrained due mostly to cost impediments along with technological limitations. Currently, solar energy represents less than 1% of total electrical capacity. For this reason, it bears reusing a figure from the previous section to illustrate the cost constraints:



* IGCC with carbon capture and storage, ** Supercritical coal. Solar PV- Solar Photovoltaic, CSP - concentrated solar power, Gas CT - Gas combustion turbine, Gas CC - Gas combined cycle, IGCC - Integrated gasification combined cycle, O&M – Operation and Maintenance

Source: World Bank, 2011

Figure 15 Levelized cost of energy in USD per MWh produced[35]

This figure illustrates the dramatic discrepancy in costs between solar and other forms of energy, and even between types of solar energy. The Egyptian NREA cites cost as a clear reason why development has not moved forward as quickly as they would hope. Figure 2 clearly illustrates the discrepancy in cost between solar and fossil fuels. But even more intriguing is the discrepancy with other renewable; solar is more expensive than wind and hydroelectric power. Solar PV is up to seven times more expensive than wind.

However, there have been several notable projects and plans blueprinted in Egypt with the goal of creating scalability over time. The following figure illustrates these project that were documented in the 2012/2013 NREA Renewable Energy Plan:

Figure 16 NREA 2012-2013 Report (latest available) Solar Plan for 2017

At this juncture, Egypt had expected to build approximately 360MW (not pictured: 20 MW from a combined Solar-Natural Gas plant), however Egypt has actually greatly exceeded these planned projects with new project proposals signed within the last few years. The following chart illustrates a few of these new project proposals.

This figure is incomplete in that many of these projects are privately funded and therefore the approximate costs are not public information. Furthermore, the expected implementation date is also an approximation. Previous renewable projects have been pushed back as a result of political instability, and so these projects should remain on schedule as long as Egyptian governance remains steady.

Project	Capacity	Cost	Expected Implementation Date
Kom Omb	200MW		~2017
SkyPower Project	3000MW	~$5 Billion	Multiphasic, phase one 2016
ACWA Project	1500MW	$205 Million	Q1 2017
Scatec Solar Project	250 MW		Multiphasic, phase one Q42015
Sterling and Wilson	300MW		Multiphasic, phase one Q3 2016

Table 4 Solar projects contracted with the Egyptian government

As is illustrated in the above table, the expected capacity and projects that are planned far exceed the 2017 projections that the NREA created. This is potentially a function of the cost of solar power decreasing at a rate faster than expected, international financing being readily available, along with regional development peaking. The Morocco solar plant as a case study illustrates all three of these phenomena.

Overall, Egypt's plans for solar development are extensive and constantly expanding. In the NREA report, several goals were placed:

- 2017: 360MW from new projects
- 2027: 3500 MW total from solar
- 2% share of solar power from Solar by 2020

It is now abundantly clear that these goals will be matched and exceeded rapidly. Egypt already has more than 5,250MW of solar power planned for the next 3 years. With new projects constantly being planned, an estimate of 2% solar share by 2020 is likely conservative, and the goal for 2027 has already been eclipsed by an enormous margin.

The Economics of Solar Power

Currently, solar power is indeed considered an expensive proposition (see Figure 3), however solar energy is continuously becoming cheaper. Vishal Shah, Managing Director at Deuche Bank and considered by many to be a foremost expert on the global solar economy, had much to say about the decrease in solar energy costs.

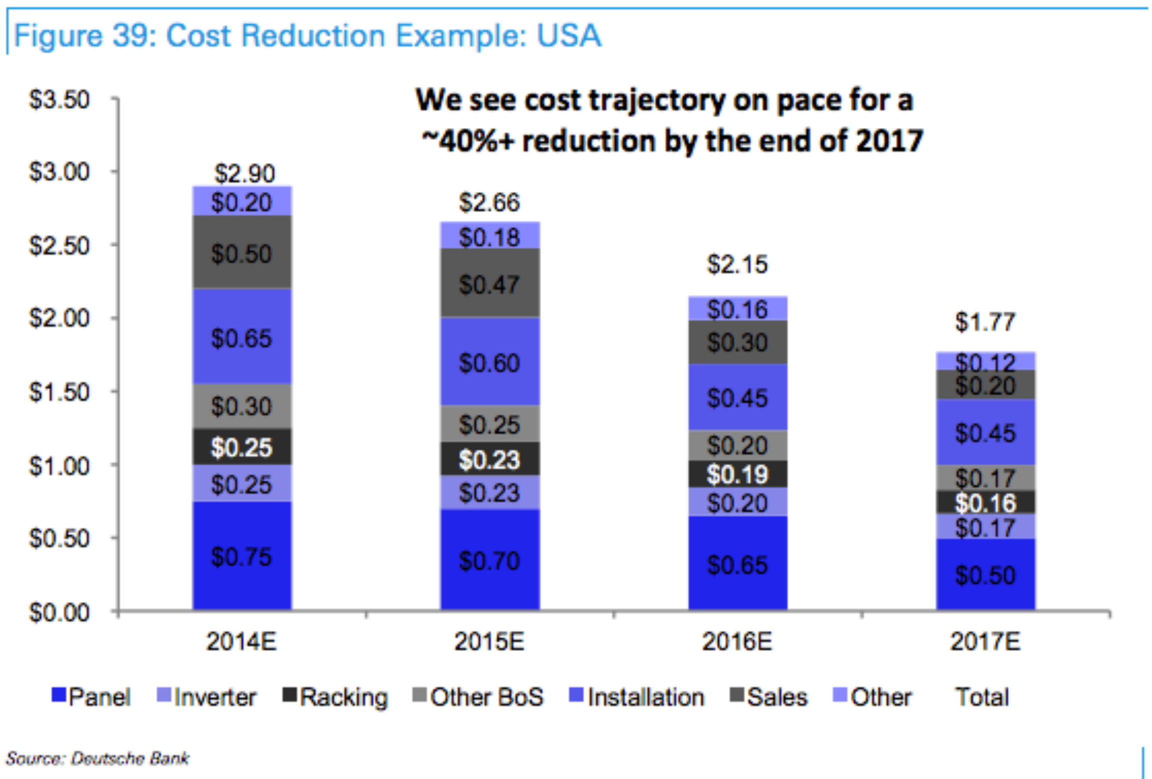


Figure 17 Reduction in solar energy costs in the U.S.[36]

Figure 17, while a United States example, shows the potential for cost reduction in solar energy[37]. The figure shows around ~40 reduction in costs by the end of 2017. This is sans-subsidy expansion. Essentially, the materials for creating solar panels has become cheaper and it is expected that they will continue to do so. Furthermore, a Goldman Sachs report indicated that solar panel supply is greatly outpacing demand currently, which could lead to even more unanticipated cost reductions if the market is oversaturated[38].

Furthermore, Shah claims that 50% of the world is now at grid parity for solar. Grid parity refers to cost for a certain type of electricity being equivalent or cheaper versus the other available forms of energy. Therefore, with this knowledge, its clear that solar grid parity is more than a realistic goal for Egypt; it's a plausibility given its relationships with solar developers and financing agents, along with its ideal solar geography.

Furthermore, storing solar energy will continue to become cheaper as well. While that is a clear limitation currently, and although solar thermal plants can temporarily store heat, there appears to be significant improvements in the field of energy storage both in terms of capacity and cost.

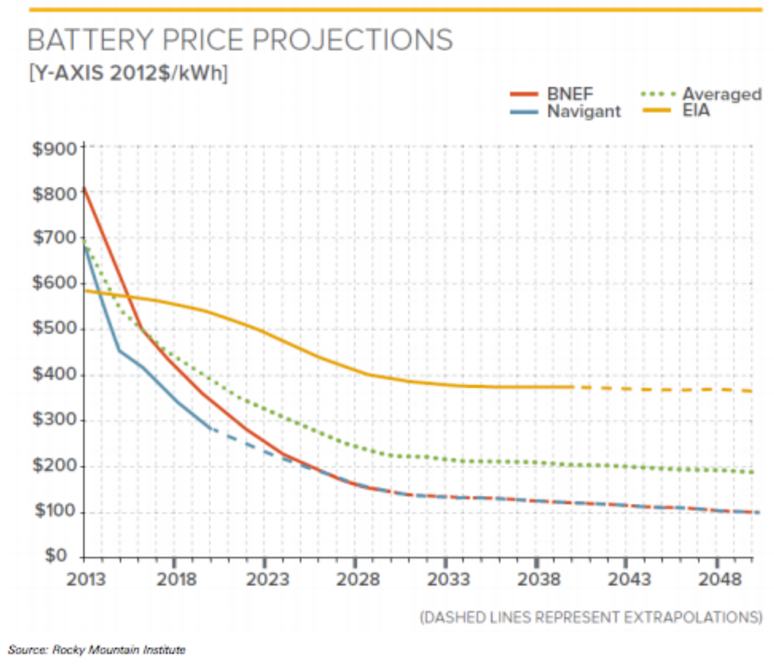


Figure 18 Blended battery price projections[39]

Figure 18 clearly shows that battery prices will continue to decrease, potentially allowing for one of the major issues with solar energy to be rectified in the form of energy storage in batteries. For developing nations such as Egypt, in need of consistent energy in areas with decentralized grids, this could prove to be an enormous innovation that allows for renewable energies, specifically solar, to service these areas.

Chapter 5

HYDROELECTRIC AND NUCLEAR POWER: POLITICAL CHALLENGES

Hydroelectric and Nuclear energy are some of the most prolific non-fossil fuel energies in terms of ubiquity and ease of adoption. However, for Egypt, both face massive political challenges moving forward.

This section will discuss both succinctly as they have the potential to change the dynamic of energy in Egypt, however both are static and/or not experiencing dramatic growth. However, the political situations surrounding them are important to consider for the broader purpose of understanding Egypt's long-term energy prospects considering the geopolitical dynamics in the MENA, along with international norms and regimes. Therefore, because of the geopolitical situations surrounding both hydroelectric and nuclear energy, in Egypt specifically, they will be discussed with less rigor and depth than solar and wind energy, but are important to mention all the same; especially as they absolutely qualify as part of the energy basket for Egypt's future and will certainly be influential in the policy recommendations at the heart of this analysis.

Hydroelectric Dilemma

Egypt's Nile Dam has been a source of hydroelectric energy since the 1950's. Currently, hydroelectric energy, which is created through the placement of turbines in areas of powerful stream or ocean current, represents approximately 9.7% of Egypt's total energy capacity.

Hydroelectric energy is considered widely to be an excellent source of renewable energy given its unlimited renewability and its high electrical output over the life of the investment. Most critiques of hydroelectric energy are focused on environmental impacts of dams, specifically with regard to the natural habitats they can potentially displace.

In the case of Egypt specifically, the issue is not with building new hydroelectric capacity, as the Nile has been taken full advantage of within the Egyptian borders. Instead, the issues lie with upstream disruptions.

Ethiopia's Grand Millennium Dam is a potential threat to the hydroelectric capacity that Egypt currently generates from the Nile[40]. Ethiopia has completed the majority of construction on the project, which will severely impede and/or slow water flow through the rest of the Nile. Potential ramifications are not only on hydroelectric energy generation, but also on irrigation systems, the Nile basin geography, potable water and local economies of Nile villages and farmers.[41]

Figure 19 Map of Nile River, highlighting Ethiopian dam[42]

The above figure illustrates the potential disaster the Grand Millennium Dam can spell for Egypt, as the majority of water that runs through the Nile originates in the Ethiopian mountains. Researchers and environmental experts agree that if unchecked, the new dam can potentially change the entire geography of the Nile basin[43], which includes several of the most populous cities in Egypt including Alexandria, which be catastrophic on a number of different levels.

Therefore, the issue at hand is maintaining the same level of economic output from the Nile and its derivatives as before this Ethiopian dam was constructed. To do this will require international cooperation and political maneuvering, however it is expected that an equitable solution will be reached that will allow for damages to be ascertained for Egypt in the case that the Millennium Dam changes the Egyptian governments ability to conduct business-as-usual.

In order to mitigate these potential issues with the new dam, it is likely that a political solution to these economic, geographic and legal problems will be needed. While Egypt has threatened to bomb the Renaissance Dam in order to force Ethiopia to yield[44], it is far more likely that Egypt and Ethiopia will be forced to come to agreement. While legal proceedings are pending, it is anticipated that both parties will engage in negotiations to create a cooperative environment for mutual investment in the region, rather than a hostile and combative situation in Northeast Africa.

Nuclear Power in Egypt

Similarly, nuclear power in Egypt can be polemical. Currently, the international community has mixed feelings over the formation of nuclear power in Egypt, especially due to the political unrest therein. Similarly, Iran faced U.N. sanctions due to the development of their nuclear energy facilities. While that is currently not the case in Egypt, depending on the progress of the political process, one could see an Islamist regime drawing the ire of the Western world with regard to nuclear development of any kind.

Currently, there are plans to develop a nuclear power plant in El Dabaa by 2022 with the support of the Russian Federation[45]. However, it is unclear how much electricity this plant would produce due to the secretive nature of the plans as of now. Furthermore, it appears that at least some of the electrical capacity will be used to repay the Russian Federation for this project, with the terms of said agreement not clear. For this reason, in nuclear energy will be excluded from later economic analysis.

Additionally, due to the history of nuclear development in Egypt, it is plausible that this project is not followed through upon[46], especially as ties between Egypt and Russia have a history of fluctuating when convenient for both parties. Furthermore, given the uncertain nature of Egypt politically, and the status of nuclear energy in the middle east as a viable option, the decision to limit nuclear energy growth in calculations is sensible.

Chapter 6

ECONOMIC ANALYSIS OF ALTERNATIVE ENERGY OPTIONS

The options presented clearly indicate that Egypt's development will be multi-faceted with regard to alternative energies. The Egyptian government and the NREA must now focus on how they can ensure that the development of these various energy sources can be capitalized upon for economic growth and, subsequently, political stability.

The economic analysis presented herein will focus on three main points. The first of these is analyzing and understanding the ideal mixture of energy production as it relates to all energy sources currently producing electrical capacity. Additionally, looking at job growth and infrastructure development that has been a byproduct of energy investment is also important to assess. Lastly, looking at energy balance and the potential for energy export will be a key aspect of this analysis. With this analysis, policy proposals will be suggested in a more informed and precise manner.

Identifying the Correct "Mix" of Energy for Egypt

An important aspect of energy policy is finding a balance between various sources of energy to enable a nation to take advantage of the various geographic advantages at its disposal for economic gain. In the case of Egypt, this amounts to several different energy classes being utilized. The "base case" or what Egypt will be building off of is a mixture of petroleum, natural gas, and the hydroelectric power it currently produces. These are the consistent drivers of Egyptian energy, with the status of natural gas in Egypt making it a growing contributor to electrical capacity.

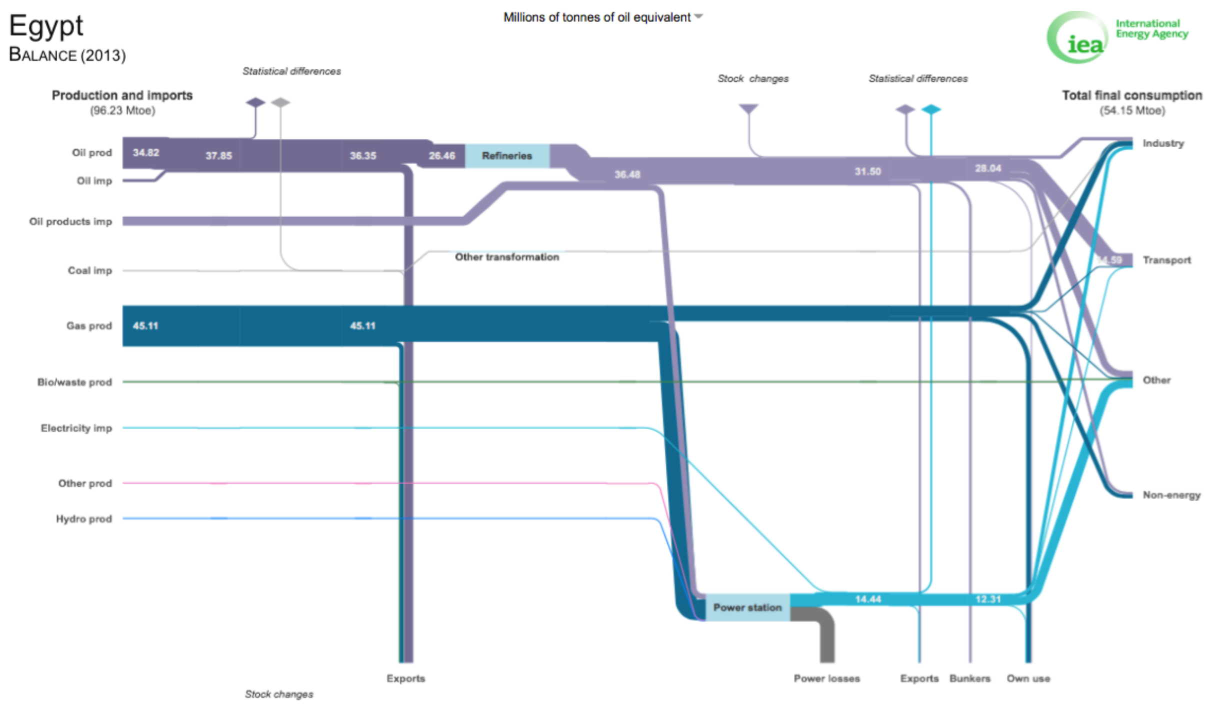


Figure 20 IEA Energy Sankey for Egypt, 2013[47]

The above figure illustrates the previous point. This energy Sankey shows the origination and destination of energy sources in Egypt. While this is the latest available iteration, it is somewhat dated in the quickly changing energy landscape of Egypt. What is important to note, however, are the three main sources of energy that served as a foundation: oil, gas, and hydroelectric.

Moving forward, it is clear that this chart will look exceedingly different in coming years. This change will be indicative of the changing mix of energy inputs and destinations. Most noticeable will be the influx of solar and wind energy, taking up a much larger percentage of the total energy produced and consumed within Egypt. So in analyzing and projecting how large a stake solar and wind power will have in the Egyptian economy, there are several key factors that will be important for their development:

- Influence of investors, incentives and profitability
- Geographic comparative advantage
- Influence of changing costs, including economies of scale
- Availability of finance options
- Political and international regime influence, including regulation and mandates

These factors essentially coalesce into how investors and stake holders view the prospects of various alternative energies in a nation, in this case – Egypt. The following chart is from the perspective of an investor, looking at the various factors that influence decision making and the development of a strategic vision dedicated to returning value to stakeholders. In the case of the government, these incentives are different, but only slightly: Egypt, as a developing nation, is clearly interested in developing business within its borders. Public-Private partnerships are a huge component of that, but with the continued development of alternative energy, Egypt is and should be more willing to allow private investment to guide the process within reason.

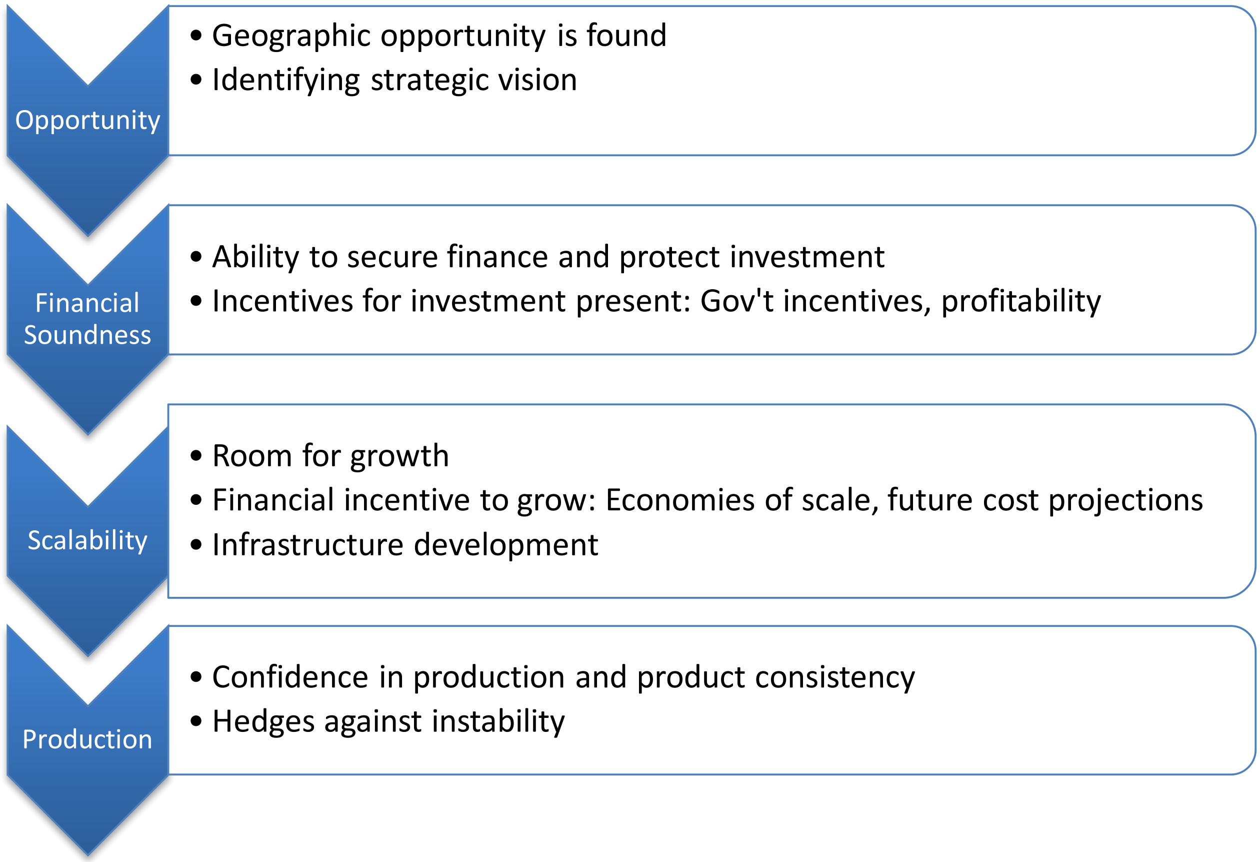


Figure 21 Decision-making flow chart of private investment in Alternative Energy

Understanding the incentives for investment, we can now begin to assess the development of Egypt's energy mix progression. In optimizing economically, typically the function utilized is a LaGrange function. However, this would be an imperfect methodology for this current problem, given the stages of development and multitude of factors that would need to be accounted for. If a LaGrange function were utilized in its basic form, it would indicate that all investment should be directed towards Natural Gas development considering its price point and ubiquity in Egypt.

Instead, a model should be created that factors in more relevant variables than simply cost, namely: profitability, future cost movement, geographic advantage, incentives, necessity of energy diversity, and mandate by government/foreign entities.

By looking analogous geographic areas to Egypt, and their precocious alternative energy development compared to Egypt's nascent alternative energy, we can create a basis for growth in Egypt. Slight variations based on other factors including new information on certain cost projections as well as government goals will be factored in to help create a 5-year outlook for alternative energy in Egypt.

California, Morocco, and Saudi Arabia are good analogues for Egyptian development for several key reasons: geographic similarity (solar and wind geographically advantageous), government emphasis and incentives, and their historical use of alternative energy to base analysis off of.

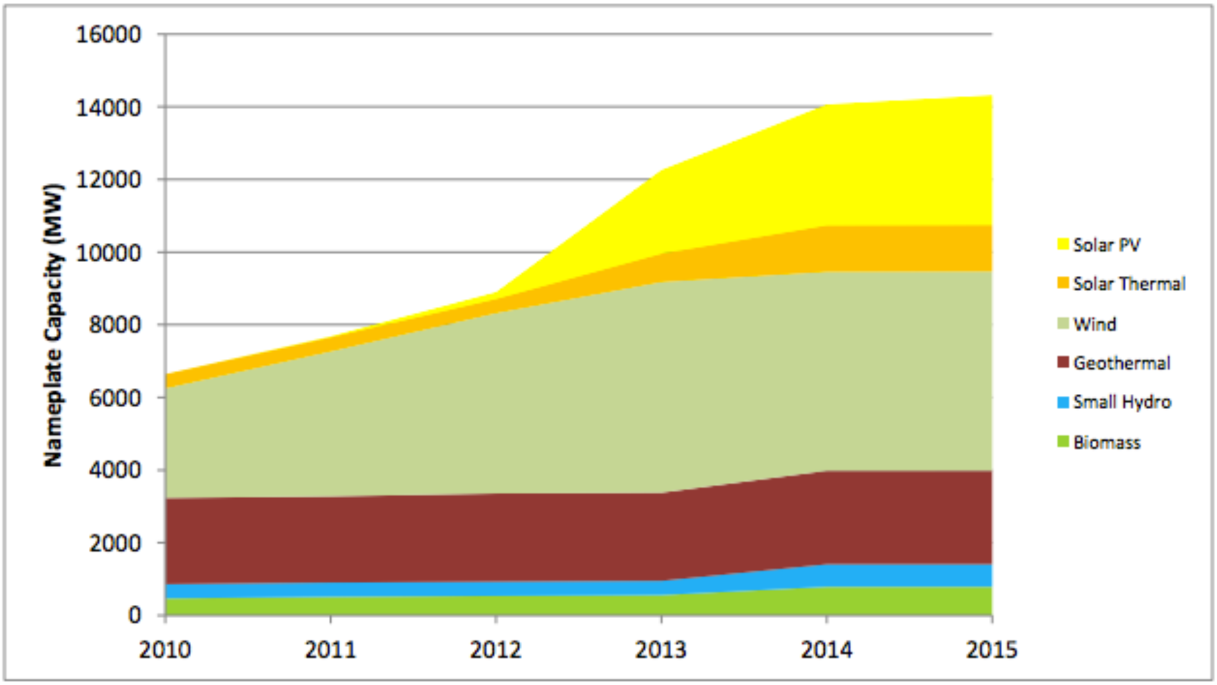


Figure 22 California Alternative Energy Growth, 2010-2015[48]

As indicated by the above figure, California's alternative energy growth, similar to Morocco and Saudi Arabia (while not pictured), begins to skew heavily towards solar energy after 2012. While wind remains steady, the constant decrease in solar energy cost is a foundational in the development of alternative energy in developing nations.

Wind energy is clearly a pivotal part of Egypt's alternative energy production in the future. By looking at the criteria that were outlined above, we can surmise that wind energy will be important given its importance in the view of the Egyptian government and the investments being made by the private sector. Furthermore, as previously discussed, wind energy has objectively a fair amount of room for growth adjacent to the Red Sea – taking advantage of economies of scale in this geographic location would be an economically sound strategy.

Additionally, solar energy growth should be expected, not only due to the geographic advantages that Egypt clearly has given its position in the sun belt, but also due to the decrease in cost of production of solar PV and solar thermal energy. In the following projections, Hydroelectric energy is held constant due to the nature of hydroelectric energy in Egypt – due to the damming of the only major waterway, there is little more hydroelectric potential to be taken out of the Nile. Further, these projections assume that an equitable solution with Ethiopia is reached to ensure that the Nile in Egypt remains in its current condition.

These projections also factor in the diminishing costs of solar, and it is viewed that this cost reduction will be more attractive to investors than the marginal increases in productivity that wind energy would see. Therefore, it is anticipated that solar will grow at a faster rate than wind energy – eventually overtaking wind as the largest alternative energy provider in Egypt.

Additionally, there are several key assumptions with these projections that are enumerated below:

- Oil prices per barrel within the $30-$60 range for the next year
- Government stability and maintained focus on alternative energy development
- Business-as-usual in natural gas production costs and growth
- Hydroelectric energy remains steady in the face of Ethiopia's dam building

Another important assumption is the presence of funding. Currently, there are three major ways in which these projects can receive funding: tax revenue, private investment, or foreign aid. While Egypt has certainly invested a lot into alternative energies, public-private partnerships appear to be the direction that the government is hoping to move towards. This comes in many forms, but in many cases, the government and a private entity collaborate in the hopes of creating a profitable venture that is simultaneously beneficial to the public. One great example of this in Egypt is the land-renting phenomenon that the government has engaged in with private entities, allowing them to use the land at an extremely low price if engaging in alternative energy production. This is one of many incentives the Egyptian government has incorporated to make the business environment more favorable. Additionally, entities such as the World Bank and IMF have been providing funding for several alternative energy projects in developing nations while also engaging as a third party to several public-private partnerships such as the ones in Egypt[49]. One role that these development banks and institutions perform is in reducing risk for the private investor in a nation that carries geopolitical risk. One way in which these institutions do so is by paying for the insurance for these projects, allowing the investors to have much less risk and therefore be much more willing to lend their capital to a project[50]. This is because, with the insurance paid for by the IMF or World Bank, the private investor now can receive at least a partial reimbursement if the project fails for political or other reasons. With geopolitical risk being one of the biggest deterrents for investment in MENA states, this third-party risk absorption can greatly improve developing nations' ability to incorporate foreign investment with higher impact. These projects could effectively be more impactful due to less inherent risk, meaning that investors could potentially be more comfortable investing more in these projects than they otherwise would be willing to.

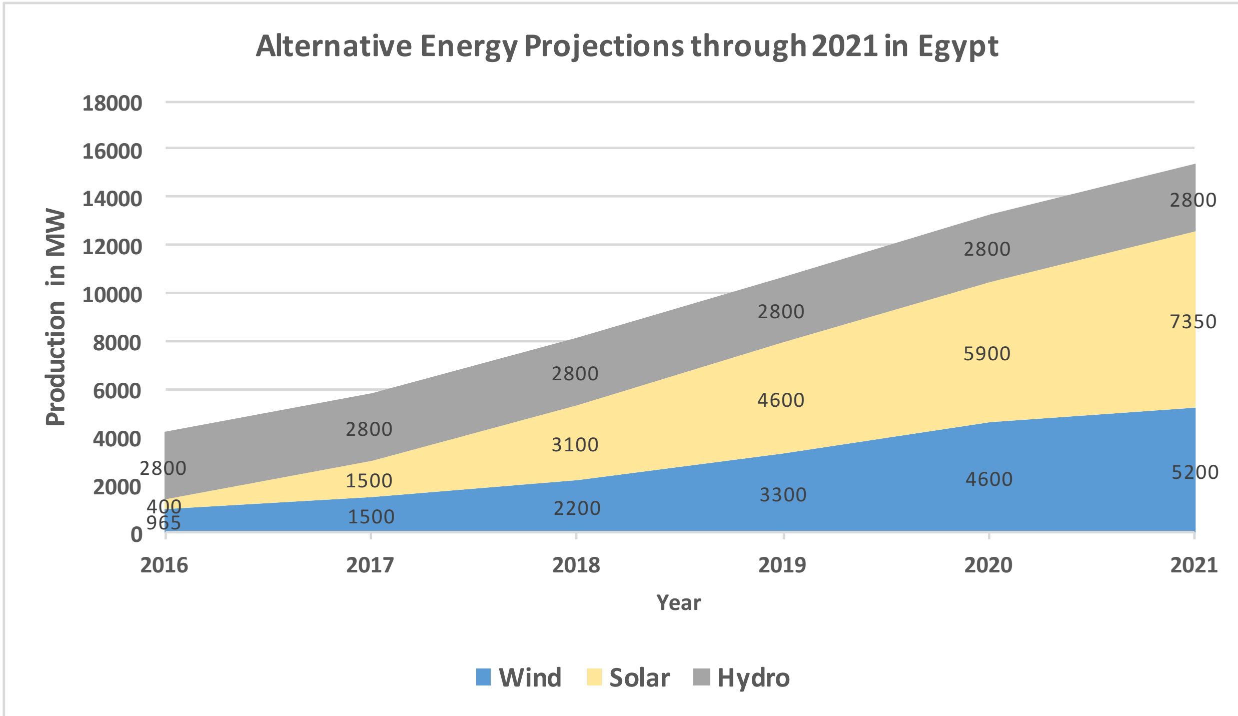


Figure 23 Author's projections of Wind, Solar, and Hydroelectric development through 2021

The projected increase from 4165MW (~4.2GW) in 2016 to 15.35GW could be an economy-altering reality for the Egyptian government and its' people. Egypt is expected to have electricity demands of 40GW by 2021, meaning that if these alternative energy projections were to be accurate, alternative energy would represent 38.375% of Egypt's total electrical demand. This can essentially allow the potential fossil fuel growth that Egypt has the capacity to undergo to serve an alternative purpose than it currently does – while most natural gas produced in Egypt is currently consumed by Egyptians, by creating large amounts of alternative energy, the entirety of the "energy base" grows, allowing natural gas to be exported at a greater rate. This is because wind and solar power can essentially take the place of natural gas domestically.

So, in projecting the potential for Egyptian net export of energy, assessing the growth of oil and gas production is also important. Over the last 10 years, oil production has grown on average of 3% per year, whereas natural gas has stagnated significantly, in part due to aging infrastructure. In projecting the growth of said fossil fuels, using the 3% figure for oil over the next 5 years seems reasonable, whereas for natural gas an assumption of no net growth makes sense due to the counteracting forces of aging infrastructure and newer concessions slowly being brought online.

Therefore, by 2021, oil production in Egypt could reach 890,000 barrels/day, which would represent, alongside current oil import-deals, 37% of Egyptian energy demand (down from 41% in 2013). Natural gas, similarly, would decrease as a percentage of consumption from 53% in 2013 to approximately 41.67% in 2021, with the 2 trillion cubic feet in production figure remaining steady. As the projections for alternative energy already show, approximately 15.35 GW of solar, wind, and hydroelectric power can be expected at peak production, representing 38.375% of Egypt's peak electrical demand. Together, this means that if import deals remain the same (in the case of several, this is necessarily the case due to contract lengths), Egypt's production and current import deals would account for approximately 117% of peak capacity. This would mean that there would be a 17% reduction in spending and/or revenue from the growth of alternative energy. Essentially, this would perform the same function either way: either spending is reduced or a profit from net export would be found. What is important is that there is economic movement from the creation of a larger capacity for energy production.

One potential issue with this is the volatility of energy prices in the international market. While assumptions were made based on current pricing, there are several scenarios that may present themselves. If, for example, the price per barrel of oil was to plummet once more to around $20 per barrel, the Egyptian government and private entities might feel less inclined to continue with high investment into alternative energies especially as the price of fossil fuels remains low. At $50 per barrel, the standard assumptions used in these projections would hold steady, and investment would most likely remain high, especially as Egypt is close to achieving grid parity even at this relatively low price point. However, at $80 per barrel, the international community would likely push for more investment due to the potential for cost-savings through wind and solar, meaning that Egypt could be at an even larger advantage than it already is with regard to the way the international energy regime is shifting.

This bodes positively for the future of the Egyptian economy. Capitalizing on private investment in these new energies with this projected growth could yield huge cost savings in the form of government spending, which could be reinvested into long-term economic priorities such as maintaining water quality, education, public health, and enhancing the corporate environment to de-militarize businesses.

Job and Infrastructure Growth

Additionally, there are several positive outcomes economically of investment in alternative energy growth outside of energy independence and potential export – job growth and infrastructure development.

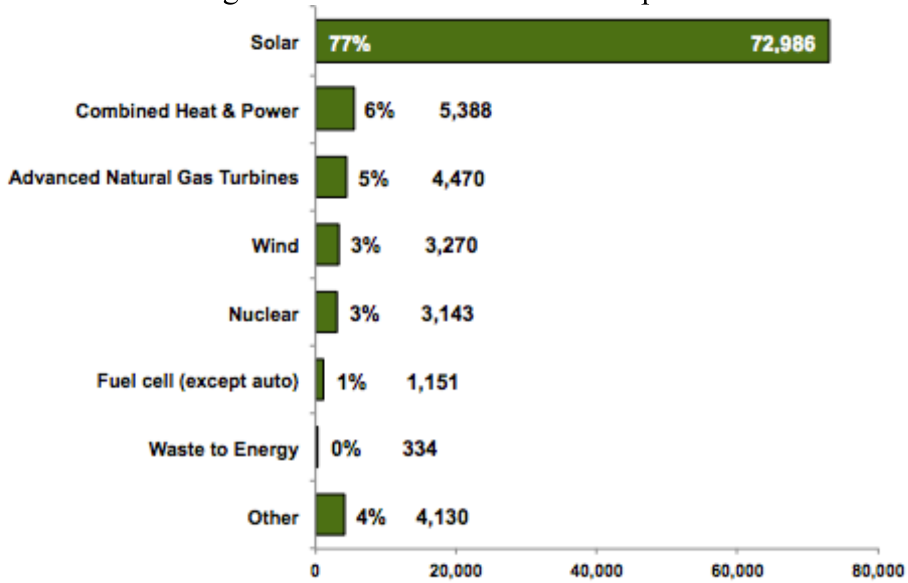


Figure 24 Employment by Alternative Energy subset in California. Source: Advanced Energy Economy Institute

While data regarding job growth projections for the planned projects in Egypt are limited due to the involvement of private corporations, several companies, namely Siemens, have used job growth as a part of their pitch to the Egyptian government for alternative energy concessions, with the opening of a wind turbine factory in Egypt potentially creating up to 1,000 jobs[51].

Once again, job growth can be modeled after California due to the similarity in policies and growth. While California has a large small-business advanced energy base, Egypt's is much more focused on foreign direct investment for alternative energy growth. Therefore, factoring this into projections, 600 jobs per GW of energy produced would be a fair approximation, with a +/- 10% variance.

This would mean that wind and solar energy growth could account for up to 7200 new jobs in Egypt. These would likely be high-quality jobs, employing manufacturers, engineers, financial professionals, and more. The externalities of this job growth would also be pivotal for an Egyptian economy that suffers from overpopulation in Cairo and Alexandria along with braindrain. Creating alternative energy jobs outside of major cities can help to begin the process of decentralizing the population, albeit in a small but tangible way. Furthermore, Egypt currently suffers extensive braindrain, with many of its most highly educated individuals leaving for Western nations. By emphasizing the growth of high-impact engineering, business, and policy positions working in the private-public sphere, the attraction for retaining highly skilled human capital is indispensable.

Infrastructure is also an enormously important component of alternative energy development. Not only does it have a direct impact on the growth and stability of the energy grid, but it also allows for ancillary infrastructure such as roads to be built. Furthermore, the access to alternative energy in geographically remote places has the potential to fuel innovation – more efficient long-distance power lines, grids, and storage are all under investigation. This innovation is pivotal in opening more land to development for solar and wind and can help make international solar and wind partnerships much more pragmatic.

Developing a wind energy project involves a wide array of activities and inputs along different segments of the value chain (Figure 8). Given that the majority of the project lifetime cost relates to the development phase, there is an incentive for governments to make efforts to support a domestic industry and localise as many activities as possible. This would create local jobs, reduce reliance on equipment and skills imports, and stimulate the local economy. For instance, between 64% and 85% of the total cost of a wind project is directed towards the turbines, which primarily include the tower, drivetrain and rotor blades. Countries have traditionally opted to produce towers and rotor blades domestically given the logistical challenges and costs associated with transporting them over long distances. The drivetrain or gearbox is a high-value component requiring advanced technological knowhow and resources to carry out regular O&M on operating systems (unlike towers and blades). Given these complexities, not all countries are willing to pursue the development of capacity to build gearboxes locally. Other segments of the value chain, such as installation and grid connection, also present potential opportunities for local value creation.

Identifying which segments of the value chain can be localised requires a careful assessment of the needs and the available resources and infrastructure. In this context, IRENA's report *Renewable Energy Benefits: Leveraging Local Industries* analyses the activities involved along different segments of the value chain of solar and wind projects. It outlines the requirements in terms of manufacturing capacities, skills, raw material availability, access to financing and the presence of an enabling environment to support the development of a domestic industry. This would assist policy makers assessing the local services and components needed to develop projects and the strategic drivers to develop renewable energy industries.

Figure 25 Box on infrastructure taken from IREA report[52]

The above figure illustrates just how synergistic alternative energy and infrastructure are. The box above refers to production, similar to the example of Siemen's wind production plant in Egypt. These facilities are a boon to local economies and alongside them, production of transit capacity, electrical capacity, and high-output value chains makes the advantage of simultaneous infrastructure and alternative energy investment apparent[53].

Chapter 7

CONCLUSION

The above analysis represents an important aspect of the economic development of Egypt. Through the opportunity presented by the abundant renewable resources within Egypt's geography, the ability for Egypt to become more independent from an energy perspective bodes very well for its future. The challenges that Egypt currently face are numerous, but expanded energy capacity, economic independence and an improving investment climate are the first steps to bringing millions of Egyptian's out of poverty.

This assessment of future energy creation in Egypt is salient for the Egyptian government and private sector investment. While it is likely that research of this kind has been conducted privately by investment firms and the like, more of this type of analysis is pivotal if Egypt wants to capitalize on the wealth of resources the nation will soon have access to. This type of research can manifest itself in the form of macroeconomic policy, national strategic thinking, and public-private partnerships. The value in this research being publicly accessible and acknowledged by the Egyptian government is in the transparent business environment that it could potentially create while attracting investors, steadying the political landscape, and creating a positive government landscape that rewards innovation and forward-looking thought.

The possibilities for Egypt remain especially intriguing as one considers the possibility that new technologies will continue to improve the efficiency and levelized cost of Solar and Wind energy. As we have seen, the cost for these technologies continues to decrease, and along with it, the cost that the Egyptian government will be incurring on energy. With lower investment costs on alternative energies and a diminishing subsidy program, the Egyptian government can leverage its tax revenue and political capital to solving truly pressing domestic issues – namely, public health, education, and geopolitical strife.

Proposals

There is clear, positive movement with regard to alternative energy development in Egypt. However, there are other certain areas in which Egypt could certainly continue to improve.

The first of which should be the maximization of wind infrastructure along the Red Sea. While solar costs continue to decrease, the concentration of wind farms along the Red Sea will continue to see diminishing costs per unit of energy produced. The ancillary infrastructure that will be used to serve these farms also will serve the nation on a long-term basis, meaning that investing in said infrastructure now will improve the business-readiness of the area without dissuading investors who are hoping for cheaper turbines in the future. This type of investment will also create jobs in a less densely populated area of Egypt, with the potential positive externality of eventually creating a more decentralized population that is otherwise concentrated in a few major cities.

Additionally, the Nile is of paramount concern to Egypt from an economic, agricultural, and environmental perspective. Entering into multi-lateral discussions with Ethiopia and other nations with a mutual interest in the interests of both states could potentially result in a deal between the states that sees Ethiopia able to utilize its dam while compensating Egypt, either monetarily or with cheap energy, to help mitigate the negative outcomes associated with the building of the Millennium Dam[54]. Currently, legal proceedings are ongoing, however, based on the dramatic impact this project may have on both states, there may be incentive to enter negotiations for both states regardless of the legal outcome and based on previous threats made by the Egyptian state[55]. Egyptian officials have previously backtracked on claims that they would consider bombing the dam if Ethiopia went through with the construction; however, this would likely result in negative outcomes for both states in the form of sanctions for Egypt and huge economic and collateral damage on the side of Ethiopia.

Also of importance is the need for international collaboration in the energy realm. Egypt and Saudi Arabia's collaboration[56] in joining parts of their grids to mitigate peak energy shortages during the summer has been effective so far, and as both nations continue to grow in their energy use, it can help both states with their efficiency and ability to meet peak demand. Therefore, it may be beneficial to expand these projects and engage in new cross-national energy production projects. Some good examples of these include the Sahara Wind Project and the proposed Sahara solar farm. Both these projects would require input from multiple states, but their production can potentially yield efficiently allocated energy for consumption or resale. For example, the Sahara Wind Project could potentially cross through Morocco and into Europe. Considering Europe's lesser ability to produce renewable energy, but higher demand from the perspective of governments hoping to reduce carbon emissions, projects that export renewable energy could potentially become very profitable for MENA states if the travel of electricity over many miles can be done in an efficient manner. It is, however, a question of scale and whether these states have the organizational capacity to conduct such large-scale projects.

Desalination is also a potential solution to Egypt's future water problem[57]. With climate change and the dependence on the Nile, being able to turn salt water into potable water could be an important part of Egypt's future. Saudi Arabia has been successful in using desalination as a solution, albeit with fossil fuels rather than solar power[58]. Egypt could take advantage of that knowledge base. Furthermore, as the cost of Solar continues to decrease, using Solar for desalination plants could prove fruitful and an efficient way of producing water, in an otherwise difficult situation.

Concluding Remarks

Moving forward, this research could be beneficial in conducting GDP growth modeling taking the new investments in alternative energy into account. This would be very helpful in understanding the development of Egypt considering the gravity of energy in the context of its economy. Furthermore, while the projections herein are favorable for the future of the economy, it's pivotal to remember that without effective governance or political stability, much of this development will be stunted, as was the case in 2010 after Mubarak was removed from power. At that time, there was a two-year delay in development due to the instability – if Egypt continues to suffer from consistent political turnover, these delays in development will push Egypt further into a state of stagnation. Lastly, Egypt needs to take climate change seriously as the effects it can potentially have on the economy, environment, and population in Egypt are vast, and for a developing nation, they will prove to be a fundamental challenge for the coming generation.

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